COLD HEARTH AND SKULL FOR REFINING METALS WHICH SEAL TOGETHER TO PREVENT OVERFLOW OF MOLTEN METAL THEREBETWEEN

BACKGROUND OF THE INVENTION

1. TECHNICAL FIELD

Generally, the invention relates to the melting and refining of metals using electron beam guns or plasma torches in a water-cooled cold retort or hearth. Particularly, the invention relates to a cold retort or hearth for producing refined ingots of metals and metal alloys in which a skull formed within a skull-receiving chamber of the retort or hearth. Specifically, the invention relates to a cold retort or hearth and associated skull that prevents molten metal from filling any gap present between the retort or hearth and the skull to damage the insulating material and reduce the effect of preventing heat loss from the skull to the retort or hearth.

2. BACKGROUND INFORMATION

Titanium is increasingly used in many design applications where material having high strength and low weight is required. One obvious example is the aircraft industry where every pound of weight reduction to an aircraft means increased range or more payload capacity. Turbine aircraft engines in particular use substantial amounts of titanium alloys in the blades and disks of the fan and

compressor sections where high strength and durability are required. These blades and disks must hold together under high stresses and heat for thousands of heating and cooling cycles as the engine is started and stopped. Failures are typically catastrophic, resulting in the engine self-destructing. One major cause of blade and disk failure is defects such as unrefined inclusions present in the titanium alloy which act as stress risers from which cracks propagate. Even the smallest amounts of unrefined inclusions in these rotating engine parts can cause catastrophic failure due to the high centrifugal force the rotating parts are subjected to during high rotational speeds of the rotating components of the fan and compressor sections. Typical defects present include high density inclusions and hard alpha particles. High density inclusions are contaminates introduced during ingot production which are of much higher density than the titanium. These defects include tungsten, tungsten carbide, tantalum, and molybdenum. Conversely, hard alpha defects are titanium particles and regions with high concentrations of interstitial alpha stabilizers such as nitrogen, oxygen, and carbon.

Cold hearth refining has been used to produce commercially pure titanium, titanium alloys and superalloys. Quality improvements result from the removal of the high density inclusions and hard alpha particles in titanium alloys. For superalloys, removal of oxide and nitride inclusions and other volatile tramp elements are the major factors of quality improvement.

One version of cold hearth refining utilizes Electron Beam Melting (EBM) wherein a plurality of electron beam guns are used to melt the titanium, called Electron Beam Cold Hearth Refining (EBCHR). Raw metal in the form of titanium sponge compacts, chips, scraps, and machine turnings from the machining of components made of titanium alloy parts is loaded into a cold retort or hearth and melted by electron beams from the electron beam guns disposed over the retort or hearth. When the molten metal contacts cooled bottom and side surfaces of the retort or hearth, the titanium alloy solidifies at the walls of the retort or hearth such that only a relatively small melt pool of molten metal remains on the skull. As additional raw metal is supplied to a retort or hearth, the electron beams melt the raw metal into the melt pool. The high density inclusions settle out of the melt pool to an interface with the skull and the now refined molten metal flows to an outlet end of the melt pool as additional raw metal is added, flowing out through a pouring spout at a front end of the hearth. Hard alpha defects are removed or dissolved in the molten titanium. The refined molten metal flows from the pouring spout into an ingot mold and solidifies into an ingot of refined metal which is subsequently removed from the mold. The method is particularly effective in removing high density inclusions and inhibiting the formation of hard alpha defects due to the fact that the molten metal continuously travels through the retort and hearth before flowing into the ingot mold. Such separation of the melting, refining and casting areas produces

a more controlled residence time of the molten metal which better eliminates inclusions by dissolution and density separation processes in the melt pool.

Another version of cold hearth refining utilizes Plasma Arc Melting (PAM) wherein a plurality of plasma torches are used to melt the titanium, called Plasma Arc Cold Hearth Refining (PACHR). The process is the same as electron beam cold hearth refining except for using the plasma torches which produce plasma plumes utilizing an inert gas.

One problem for hearth refining is the low thermal efficiency for melting and refining of metals in the cold hearth typically used for EBM and PAM. A significant amount of the heat input to the skull is lost from the top surface of the skull and molten metal pool due to radiation (both EBM and PAM) and helium/argon gas convection (PAM only). The contact between respective bottom, side, and end surfaces of the skull with the water cooled copper reort or hearth results in a large quantity of heat lost to the cooling water (both EBM and PAM). As a result, high power input from plasma torch (PAM) or electron beam gun (EBM) is required to maintain a desired raw metal melting rate, liquid metal superheat, and molten metal pool volume.

In Yu and Spadafora U.S. Patent "Insulated Cold Hearth for Refining Metals Having Improved Thermal Efficiency", a method is described for solving the above-mentioned problems by applying insulating material into the gap

between the skull and the water-cooled retort or hearth to prevent heat loss from the skull to the water-cooled retort or hearth and retain heat in the skull. One problem for this invention is where molten metal in the melt pool overflows into the gap between the skull and the retort or hearth damaging the insulating material and reducing the effect of insulation.

BRIEF SUMMARY OF THE INVENTION

Objectives of the invention include providing a cold retort or hearth and skull which seal against overflowing of the molten metal into the gap therebetween during the refining process.

Another objective is to provide a skull which may be used with existing cold retorts or hearths which seals against the rim thereof to prevent overflowing of the molten metal into the gap therebetween during the refining process.

These objectives and advantages are obtained by the improved recessed rim cold retort or hearth and flanged skull of the present invention for producing refined metal from raw metal contaminated with high density inclusions and/or hard alpha particles, the general nature of which may be stated as including: a cold retort or hearth and a flanged skull. The retort or hearth has a hollowed body with a cooled interior surface which defines an upwardly open skull-receiving chamber terminating at an upper rim. The chamber holds the flanged skull of the refined metal formed in the retort or hearth. The retort or hearth is

preferably of conventional rectangular configuration, having a bottom wall, a pair of side opposing walls, and respective input and output end walls, and water-cooled using water pipes disposed in the walls.

The flanged skull is made of refined metal formed in the hearth of a shape corresponding to the chamber by molten metal contained therein which solidifies due to contact with the cooled interior surface of the retort or hearth. The skull has an outwardly extending upper peripheral flange of solidified metal which overlaps and rests on the upper rim to support the skull within the retort or hearth. The peripheral flange seals against the upper rim such that refined molten metal disposed in a melt pool formed on the skull during metal refining is prevented from overflowing into any gap present between the skull and the retort or hearth. The upper rim of the retort or hearth preferably has an upwardly open, inwardly disposed peripheral recess to receive the peripheral flange of the skull, comprising a recessed rim cold retort or hearth, though the flanged skull may be used with conventional cold retort or hearth which have no peripheral recess. The flanged skull is preferably rectangular in configuration to fit retort or hearth of conventional rectangular configuration with or without the peripheral recess.

The recessed rim cold retort or hearth and flanged skull are utilized as part of a cold hearth metal refining system for producing refined metal from raw metal contaminated with high density inclusions and/or hard alpha particles. A

preferred metal refining system includes the recessed rim cold retort or hearth used with the flanged skull, at least one heating device, an input feed device, and an ingot casting device. The recessed rim cold retort or hearth holds the flanged skull of refined metal formed in the retort or hearth. The heating device is disposed above the retort or hearth and produce heating electron beam (EBM) or plasma plume (PAM) directed onto the skull. The input feed device feeds raw metals to be refined onto the skull disposed in the retort or hearth. The ingot casting device to receive refined molten metal from the hearth and form solid ingot thereof.

The recessed rim cold retort or hearth and flanged skull are utilized in a method for refining metals contaminated with high density inclusions and/or hard alpha particles which includes the steps of: 1) providing a cold retort or hearth having a hollowed body with cooled interior surface which defines an upwardly open skull-receiving chamber terminating at an upper rim; 2) applying insulating material next on the interior surface of the cold retort or hearth; 3) providing a flanged skull having a peripheral flange to overlap and rest on an upper rim of the cold retort or hearth to support the skull within the retort or hearth and seal thereagainst such that refined molten metal disposed in a melt pool formed on the skull during metal refining is prevented from overflowing into any gap present between the skull and the retort or hearth; 4) supplying raw metal which includes high density inclusions and/or hard alpha particles to be refined therefrom into

the retort or hearth; 5) melting the raw metal in the retort or hearth using at least one heating device which produces a heating electron beam (EBM) or plasma plume (PAM) directed onto the skull to form a melt pool of molten metal on the skull having an input end and an outlet end; 6) maintaining the molten metal in a molten state a sufficient amount of time to permit impurities of a higher density than the metal to settle out in the melt pool to produce a refined molten metal; 7) transferring the refined molten metal in a molten state into an ingot mold and allowing to cool to form a solid ingot; and 8) removing the ingot from the ingot mold. The retort or hearth is preferably a recessed rim cold retort or hearth having an upwardly open, inwardly disposed peripheral recess adapted to receive the peripheral flange of the skull.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The preferred embodiments of the invention, illustrative of the best mode in which applicant has contemplated applying the principles, are set forth in the following description and are shown in the drawings and are particularly and distinctly pointed out and set forth in the appended claims.

FIG. 1 is a perspective view of a conventional cold hearth and ingot casting mold;

FIG. 2 is a longitudinal vertical sectional view of the cold hearth and ingot casting mold of FIG. 1; and

FIG. 3 is a longitudinal vertical sectional view of the recessed rim cold hearth of the present invention when a cold flanged skull of the present invention is placed in a recessed rim cold hearth showing the gaps between the flanged skull and the recessed rim cold hearth.

Similar numerals refer to similar parts throughout the drawings.

DETAILED DESCRIPTION OF THE INVENTION

FIGS. 1 and 2 depict a conventional cold hearth metal refining system, designated generally at 20, for producing refined metal from raw metals such as sponge and machine turnings of the metal, typically titanium based, contaminated with high density inclusions and/or hard alpha particles (collectively referred to as high density inclusions).

The metal refining system 20 includes a conventional cold hearth 23, typically of the water-cooled type, and an ingot casting device preferably comprising an ingot casting mold 26. The hearth 23 is a hollowed body of rectangular configuration, comprising a rectangular bottom wall 32 and an upstanding peripheral wall which includes a rectangular input end wall 35, a rectangular output end wall 38, and a pair of rectangular side walls 41 and 44. A cooled interior surface 45 of hearth 23 defines an upwardly open, skull-

receiving chamber 47 of rectangular configuration terminating at an upper rim 50. The walls 32, 35, 38, 41, and 44 are made of copper or copper alloy with a plurality of cooling pipes 53 contained therewithin through which cooling water may be circulated from a water source (not shown) to cool the interior surface 45. The hearth 23 holds a skull 56 of the metal being refined formed in the hearth 23 by contact and solidification on the cooled interior surface 45 in the present or in previous melting operations. The skull 56 includes an upper portion 59 and a bottom portion 62 both of which include generally horizontally-disposed areas containing contaminates 65 that are heavier than the metal and which settle out when the metal is in a molten state.

One or more heating devices 68, typically of the plasma torch (PAM) or electron beam gun (EBM) type, are disposed above the hearth 23 each of which produce a heating electron beam (EBM) or plasma plume (PAM) 71 directed onto the skull 56 to form a melt pool 74 of molten metal on the skull 56. The heating devices 68 are positioned at fixed positions to direct the heating electron beam (EBM) or plasma plume (PAM) 71 onto the skull 56 to form the melt pool 74. Raw metal 77 to be refined, such as titanium scraps, titanium sponges and machine turnings, is fed from a raw metal source (not shown) over the input wall 35 at a back end 78 of the hearth 23 into an input end 80 of the melt pool 74 by an input feed device 83. The raw metal 77 is melted in the melt pool 74 by the heating electron beam (EBM) or plasma plume (PAM) 71 such that the heavier

contaminates 65 fall to a bottom interface 86 of the melt pool 74 with the skull 56 forming refined molten metal at the top of melt pool 74. The vertical level of a surface 89 of the melt pool 74 rises as the raw metal 77 enters the melt pool 74 and refined molten metal overflows from an output end 92 of melt pool 74 disposed at a front end 93 of the hearth 23 through a pouring lip 95 of the output end wall 38 into the ingot casting mold 26.

The ingot casting mold 26 is cylindrical in cross-section, though it may be rectangular, polygonal, or other such shape, comprising an upright side wall 98 of circular cross-section. Side wall 98 has an open upper end 101 and an open lower end 104 which defines an interior bore 107. The wall 98 is made of copper or copper alloy with a plurality of cooling pipes 110 contained therewithin through which cooling water may be circulated. A vertically movable piston 113 closely fits abutting mold 26 to initially close the lower end 104 for containing the refined molten metal which overflows through pouring lip 95, forming an overflow pool 116 of the refined molten metal within bore 107. Piston 113 is vertically movable by an attached piston rod 119. A solid cylindrical ingot 122 of refined metal is formed within bore 107 as cooling of the overflow pool 116 progresses, and the piston 113 is gradually lowered below the lower end 104 of ingot casting mold 26 to permit forming of the ingot 122 to a desired length.

An heating device 125 comprising a plasma torch (PAM) or electron beam gun (EBM) similar to heating device 68 is disposed above the ingot

casting mold 26 and produces a heating electron beam (EBM) or plasma plume (PAM) 128 directed into the overflow pool 116 to control the rate of cooling thereof to harden into ingot 122. When the ingot 122 is of the desired length, the addition of raw metal 77 into hearth 23 is temporarily ceased, stopping the overflow of the refined molten metal into ingot casting mold 26. The overflow pool 116 is permitted to harden at a controlled rate using heating device 125 and the piston 113 is lowered to allow ingot 122 to be removed from ingot casting mold 26.

A problem with the prior art arrangement is that during the melting and refining process, molten metal from the melt pool 74 may overflow and fall into the gap (not shown) between the skull 56 and the hearth 23. When this happens, the insulating material in the gap may be damaged and the insulation effect which prevents the heat loss from the skull to the hearth may be reduced.

FIG. 3 depicts a recessed rim cold hearth of the present invention, designated generally at 131, with a flanged skull 134 of the present invention. The hearth 131 may be used as part of the cold hearth metal refining system 20. The hearth 131 is a hollowed body of rectangular configuration, comprising a rectangular bottom wall 137 and an upstanding peripheral wall which includes a rectangular input end wall (not shown) having an upper recess, a rectangular output end wall 140 having an upper recess 143, and a pair of rectangular side walls 146 and 149 having respective upper recesses 152 and 155. A cooled

interior surface 157 of hearth 131 defines an upwardly open, skull-receiving chamber 158 of rectangular configuration terminating at an upper rim 161 having an upwardly open, inwardly disposed peripheral recess 162 comprised of the recesses including recesses143, 152, and 155. The walls 137, 140, 146, and 149 are preferably made of copper or copper alloy with a plurality of cooling pipes 164 contained therewithin through which cooling water may be circulated from a water source (not shown) to cool the interior surface 157. The peripheral recess 162 includes a horizontally-disposed seal surface 165 and a vertically-disposed surface 166 abutting the seal surface 165 at a ninety-degree included angle.

The hearth 131 holds a flanged skull 134 of the metal being refined formed in the hearth 131 by contact and solidification on the cooled interior surface 157 in the present or in previous melting operations. The flanged skull 134 includes an upper portion 167 with an outwardly extending peripheral lip or flange 170 with a horizontally-disposed seal surface 171 which juxtaposes the seal surface 165 of the peripheral recess 162 of hearth 131to support the skull 134 within the hearth 131 and seal thereagainst, and a vertically-disposed surface 172 abutting the seal surface 171 at a ninety-degree included angle. The flanged skull 134 further includes a bottom portion 173 which together with upper portion 167 include generally horizontally-disposed areas containing contaminates 65 that are heavier than the metal and which settle out when the

metal is in a molten state. The flanged skull 134 forms when raw metal 77 is melted in an initially empty hearth 131 and takes on the configuration of the chamber 158 including the peripheral recess 162. Alternatively, the flanged skull 134 forms when a conventional non-flanged skull 56 is placed in the hearth 131 and molten metal from the melt pool 74 overflows into the peripheral recesses 162 forming the peripheral lip 170. Additionally, flange skull 134 may be machined out of an existing skull for use in the hearth 131. The peripheral lip 170 solidifies due to the direct contact with the hearth 23 which is cooled by water running through the pipes 164, and is not easily melted by the plasma plume (PAM) or electron beam (EBM), and hence stays in solid form during the entire melting and refining cycle. Respective peripheral rim and side gaps 176 and 179, and a bottom gap 182 are generally present during the refining process. Spacers (not shown) may be utilized between the hearth 23 and the skull 134 for support or to maintain the gaps 176, 179, and 182. The peripheral lip 170 overlaps the upper rim 161, fitting into the peripheral recess 162 comprised of the upper recesses including upper recesses 143, 152, 155, to support the flanged skull 134 within hearth 131 and seal thereagainst. This prevents molten metal disposed in the melt pool 74 formed on the skull 56 during metal refining from overflowing into any of the gaps 176, 179, and 182 present between the skull 134 and the hearth 131. Alternatively, peripheral lip 170 of flange skull 134 may be positioned directly on the upper surface of hearth

131, with no recess being provided therein. In this manner, the flange would seal directly against the traditional hearth and no recess would be provided without departing from the spirit of the present invention. Still further, flange skull 134 may be formed as above, or alternatively, a traditional skull may be manufactured with lips machined thereon without departing from the spirit of the present invention. Still further, a separate sealing ring may be positioned around the perimeter of skull 134 in order to provide a sealing ring between skull 134 and hearth 131 without departing from the spirit of the present invention.

A method for improving the thermal efficiency of refining metals contaminated with high density inclusions and/or hard alpha particles includes first providing a cold hearth and a flanged skull of the type described above having an outwardly extending upper peripheral flange of solidified metal adapted to overlap the upper rim of the hearth to support the skull within the hearth and seal thereagainst such that refined molten metal disposed in a melt pool formed on the skull during metal refining is prevented from overflowing into any gap present between the skull and the hearth. An upper portion of the skull is melted to form a melt pool of molten metal on the skull using a heating device which produces a heating electron beam (EBM) or plasma plume (PAM) directed onto the skull. The melt pool has an input end where raw metal to be refined is added and melted and an outlet end where refined metal exits the hearth. Raw metal is supplied which includes high density inclusions and/or

hard alpha particles to be refined therefrom to the input end of the melt pool and melted into the melt pool using the heating device. The molten metal is maintained in a molten state in the melt pool on the skull using the heating device a sufficient amount of time to permit the higher density impurities to settle out in the melt pool. The impurities form a layer on a bottom interface of the melt pool with the skull to produce a refined molten metal thereabove. The refined molten metal is transferred from the hearth while being maintained in a molten state into an ingot mold. The refined molten metal is allowed to cool to form a solid ingot of refined metal in the ingot mold. The solid ingot is removed from the ingot mold. The upper rim of the hearth preferably has an upwardly open, inwardly disposed peripheral recess adapted to receive the peripheral flange of the skull.

Accordingly, the recessed rim cold hearth and skull provide a seal against overflowing of the molten metal into the gap therebetween during the refining process, may be used with existing cold hearths which seals against the rim thereof to prevent overflowing of the molten metal into the gap therebetween during the refining process, the skull is easily removable from the hearth upon completion of the refining process, and is producible by retrofitting existing cold hearths which achieves all the enumerated objectives, provides for eliminating difficulties encountered with prior art devices, and solves problems and obtains new results in the art.

References for the present invention include the following documents with the most pertinent pages cited, which documents are herein incorporated by reference in their entirety: 1) C.E. Shamblen, G.B. Hunter, "Titanium Base Alloys Clean Melt Process Development", Proceedings of the 1989 Vacuum Metallurgy Conference on the Melting and Processing of Specialty Materials, Iron and Steel Society, Inc., Warrendale, PA, pp. 3-11, 1989; 2) D.J. Tilly, C.E. Shamblen, W.H. Buttrill, "Premium Quality Ti Alloy Production: HM+VAR Status", Proceedings of the 1997 International Symposium on Liquid Metal Processing and Casting, A. Mitchell, P. Auburtin, eds., Vacuum Metallurgy Division, American Vacuum Society, Santa Fe, NM, pp. 85-96, 1997; 3) C.E. Shamblen, DJ Tilly, "Inclusion Free Titanium Material Efforts", Proceedings of the Electron Beam Melting and Refining Conference - State of the Art 1997, R. Bakish, ed., Bakish Materials Corporation, Reno, NV, pp. 39-47, 1997; 4) K.O. Yu, "Plasma Arc Melting for Titanium Alloys", Proceedings of the Technical Program from the 1998 International Conference, International Titanium Association, Monte Carlo, Monaco, pp. 371-385, 1998; 5) K.O. Yu, J.G. Ferrero, C.M. Bugle, "Evaluation of the TMP Behavior of PAM Cast Ti6Al-4V and Its Effect on Microstructure and Mechanical Properties", 12th Advanced Aerospace Materials and Processes Conference & Exposition, Long Beach, CA, 2001; and 6) K.O. Yu, F.P. Spadafora, J.M. Hjelm, B. Martin, S. Fellows, and M. Jacques, "Plasma Arc Melting of Titanium Alloys for Non-Rotating Component Applications",

Proceedings of the 2001 International Symposium on Liquid Metal Processing and Casting, A. Mitchell, J. Van Den Avyle, eds., Vacuum Metallurgy Division, American Vacuum Society, Santa Fe, NM, pp. 1-17, 2001.

In the foregoing description, certain terms have been used for brevity, clearness and understanding; but no unnecessary limitations are to be implied therefrom beyond the requirements of the prior art, because such terms are used for descriptive purposes and are intended to be broadly construed.

Moreover, the description and illustration of the invention is by way of example, and the scope of the invention is not limited to the exact details shown or described.

Having now described the features, discoveries and principles of the invention, the manner in which the improved recessed rim cold hearth, flanged skull, and method for refining metals is constructed and used, the characteristics of the construction, and the advantageous, new and useful results obtained; the new and useful structures, devices, elements, arrangements, parts and combinations, are set forth in the appended claims.